Geometrical information on the solar shape: high precision results with SDO/HMI

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Abstract. The uncertainty of measurement of solar diameter is depending on the observational time scale. Full-disc images of SDO/HMI and the images from ground observations in Huairou Solar Observing Station have been analyzed to get the values of solar diameter. The satellite observations reach a very high precision, but the absolute image scale still need to be calibrated. The solar oblateness is a more challenging measurement than the diameter, since the signal amplitude is a few milli-arcseconds. It is a relative measurement, then not affected by the pixel scale calibration required by the diameter measurement. But the results are strongly dependent on the state of instrument such as focus plane deformation and on the calculation process.

1. Introduction

The ground based solar diameter measurement have been performed since very long time (e.g. Thuillier, G. et al., 2005; Lefebvre, S. et al., 2006; Sigismondi, 2011). Generally speaking, the study of solar diameter should be based on long term series of observations since it is a quite stable quantity, representative of the whole star, or of its outer shells. A global observation network to monitor the solar diameter can be realized by different cross-calibrated full-disc solar telescopes. When we compare the solar diameter observation results acquired by Huairou Solar Observing Station from 2006 to 2009 (not shown in this paper) with the results acquired by SDO/HMI in one year (2011), we find the solar diameter results based on ground observation largely affected by Earth atmospheric conditions. Conversely the space result accuracy is strongly dependent on the orbital parameters (Fig. 1).

2. Measurements of the solar diameter

The solar diameter (radius) observations on the space are continuous when the instrument is in normal operation. We used the HMI continuum images in the following discussion since its focal plane devices reach very high performance. We choosed 365 images from one year data set. But we used higher cadence (1 frame/3hour) around the perihelion, in order to check the effects of SDO Earth-rotation synchronous orbit to the apparent solar radius measures. Further, we normalize the apparent solar radii to the distance of 1 AU according to the HMI images informations (the distance satellite-Sun seems to be very accurately determined), and to its one-year average. In this way we can only see variations below one year of timescale down to 45 s. This value varies smoothly (at the moment we are not sure it is due to the approximations used in orbital calculation or it is due to a real measurement of orbit). But the pixel scale and the focus step
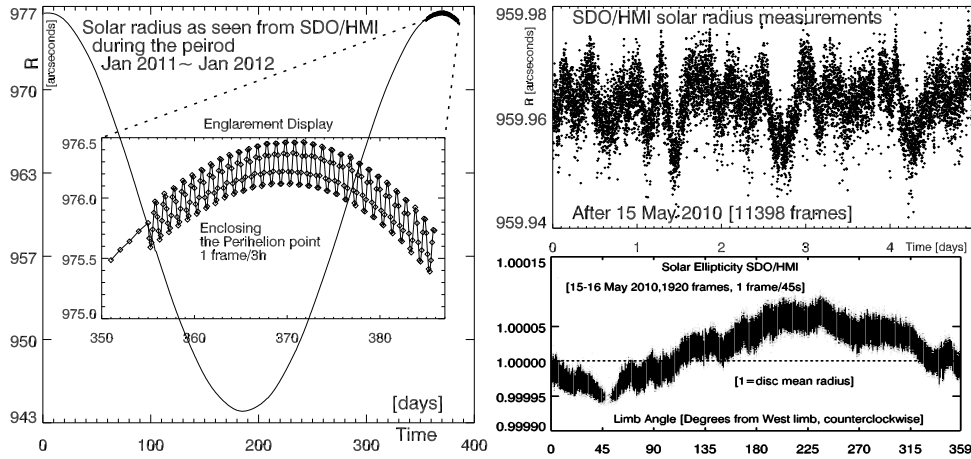
Figure 1. The apparent solar radius affected by the Earth orbital motion and the satellite orbital motion (left image with enlargement). The solar radius appears as a fluctuating signal when the orbital motions are removed (upper-right image), and there is still some orbital motion residuals. The apparent shape of solar disc calculated from 1920 full-disc images on very quiet activity period (15-16 May 2010) shows slightly departures from the sphere (lower-right image), but some invisible solar structures or instrumental problems may influence the results seriously.

parameters (see e.g. Khun et al., 1998; Emilio et al., 2012) are observational conditions which also are depending on the satellite orbit, and their precision seem to be worse than the nominal ones. Solar oblateness (ellipticity) is a difficult topic, more related to the dynamics and physics of the solar interior. The absolute pixel calibration, orbit information, and focus step are no longer essential, but flat field, focus plane deformation, and CCD small tip-tilt can affect seriously this measure. Rolling the telescope is a fair solution for such instrumental problems (Emilio et al., 2007 and 2012). To locate weighted inflexion points of the solar limb we used, as Emilio et al. (2012), polar coordinates transform of limb stripes with a bilinear interpolation, while Kuhn et al. (1998) decomposed the solar limb position and brightness into a linear combination of Legendre polynomials.

3. Conclusions

(a) The solar radius averaged over one year in our analysis is 959.963 ± 0.005 arcsec $(1\ \sigma)$. It is 0.333 arcsec larger than the standard value (959.63 arcsec) and $2\ \sigma$ smaller than 960.12 ± 0.12 arcsec of Emilio et al. (2012). Higher accuracy could depend on better orbit information, better data set (single wavelength), and absolute pixel scale calibration using Mercury and Venus transits (Sigismondi and Wang, 2013); Averages over shorter timescales can be done. **(b)** The oblateness is just a preliminary result (roughly estimate, 0.048 ± 0.03 arcsec (1σ)) since the deformation of focus plane is unknown.

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